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AERODYNAMIC CHARACTERISTICS OF AN EJECTION SEAT ESCAPE SYSTEM WITH COLD FLOW ROCKET PLUME SIMULATION AT MACH NUMBERS FROM 0.6 THROUGH 1.5

David E. A. Reichenau

ARO, Inc.

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October 1969

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AERODYNAMIC CHARACTERISTICS OF AN EJECTION SEAT ESCAPE SYSTEM WITH COLD FLOW ROCKET PLUME SIMULATION AT MACH NUMBERS FROM 0.6 THROUGH 1.5

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FOREWORD

The work reported herein was sponsored by the Air Force Flight Dynamics Laboratory (AFFDL), Air Force Systems Command (AFSC), Wright-Patterson Air Force Base, Ohio, under Program Element 62201F, Project 1362.

The results of the tests were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), AFSC, Arnold Air Force Station, Tennessee, under Contract F40600-69-C-0001. The test was conducted in the Propulsion Wind Tunnel, Transonic (16T) from June 19 to July 3, 1969, under ARO Project No. PB0746. The manuscript was submitted for publication on September 5, 1969.

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This technical report has been reviewed and is approved.

George F. Garey Major, USAF Acting AF Representative, PWT Directorate of Test	Roy R. Croy, Jr. Colonel, USAF Director of Test

ABSTRACT

A test was conducted in the 16-ft transonic wind tunnel of the Propulsion Wind Tunnel Facility to determine the aerodynamic characteristics of a 0.5-scale ejection seat escape system with a dummy crew member attached during simulated rocket-off and rocket-on conditions. Results were obtained at free-stream Mach numbers of 0.6, 0.9, 1.2, and 1.5 through a model angle-of-attack range of 360 deg and model yaw angles up to 45 deg. High pressure air was used to simulate the escape rocket jet plume at altitudes from sea level to 40,000 ft. The results show that the simulated high altitude jet plumes produced large variations of model forces when the jet was pointed upstream.

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NOMENCLATURE

b	Model reference length, 2.0 ft
C_A	Axial-force coefficient, $F_A/q_\infty S$
C_ℓ	Rolling-moment coefficient, $M_\ell/q_\infty Sb$
C_m	Pitching-moment coefficient, $M_m/q_\infty Sb$
C_N	Normal-force coefficient, $F_N/q_\infty S$
C_n	Yawing-moment coefficient, $M_n/q_\infty Sb$
C_Y	Side-force coefficient, $F_Y/q_\infty S$
F_A	Axial force, lb
F_N	Normal force, lb
F_Y	Side force, lb
M_ℓ	Rolling moment, ft-lb
M_m	Pitching moment, ft-lb
M_n	Yawing moment, ft-lb

M_∞	Free-stream Mach number
p_c	Nozzle total pressure (chamber pressure), psf
p_∞	Free-stream static pressure, psf
q_∞	Free-stream dynamic pressure, psf
S	Model reference area, 1.73 ft^2
α	Angle of attack, deg
ψ	Angle of yaw, deg

CONFIGURATION NOMENCLATURE

Arm position 1	Holding the ejection handle control on the arm rests (Fig. 4a)
Arm position 2	Holding the "D" ring control between the legs (Fig. 4b)
Arm position 3	Holding a face curtain control (Fig. 4c)
Model-sting position 1	Installation required to obtain angles of attack from 0 to 120 deg (Fig. 6a)
Model-sting position 2	Installation required to obtain angles of attack from 120 to 240 deg (Fig. 6b)
Model-sting position 2	Installation required to obtain angles of attack from 240 to 360 deg (Fig. 6c)

Note: The force and moment coefficients are in the body axis system (Fig. 7).

SECTION I
INTRODUCTION

Many ejection seat wind tunnel tests have been conducted to supply data for ejection seat design. However, the amount of test data available with the actual or simulated rocket jet is very limited and is the result of extrapolation from other data. Therefore, data that show the aerodynamic interference effects of a catapult rocket plume on ejection seat aerodynamic characteristics will be very useful for predicting the trajectory of the ejection seat, for determining the g-loads on the seat occupant, and also for designing of future ejection systems.

This report presents some typical results of tests conducted to determine the aerodynamic characteristics of an ejection seat escape system with an attached dummy crew member during simulated rocket-off and rocket-on conditions. Static-force data were obtained at Mach numbers of 0.6, 0.9, 1.2, and 1.5 for model angles of attack from 0 to 360 deg and yaw angles from 0 to 45 deg. High pressure air was used to simulate the escape rocket jet plume at altitudes from sea level to 40,000 ft. The effects, on model aerodynamics, of three arm positions to simulate different ejection techniques were also investigated.

SECTION II
APPARATUS

2.1 TEST FACILITY

Propulsion Wind Tunnel, Transonic (16T) is a closed-circuit, continuous flow wind tunnel capable of being operated at Mach numbers from 0.55 to 1.60. The test section is 16 by 16 ft in cross section and 40 ft long. The tunnel can be operated within a stagnation pressure range from 60 to 4000 psfa, depending on the Mach number. Stagnation temperature can be varied from an average minimum of about 80 deg to a maximum of 160°F. Perforated walls in the test section allow continuous operation through the Mach number range with a minimum of wall interference.

Details of the test section showing the model location and support system arrangement are presented in Fig. 1 (Appendix). A wind tunnel installation photograph showing the model at various attitudes is shown in Fig. 2. A more extensive description of the tunnel and its operating characteristics is contained in the Test Facilities Handbook.[1]

2.2 TEST ARTICLE

The model tested consisted of a 0.5-scale representation of an ejection seat escape system occupied by a crew member of average size in normal flying clothes and equipment. The model has a frontal area of 1.73 ft^2 and a side area of 1.71 ft^2. Major

[1]Test Facilities Handbook (7th Edition). "Propulsion Wind Tunnel Facility, Vol. 5." Arnold Engineering Development Center, July 1968.

dimensions of the model are presented in Fig. 3. The escape rocket nozzle was positioned in the lower aft portion of the seat (Fig. 2) and was attached to the sting so that the model was isolated from the jet reaction force.

The crew member was constructed of glass cloth impregnated with phenolic resin and was rigidly attached to the metal seat housing a six-component balance. The arms of the dummy crew member were replaceable in order to simulate three different ejection positions: arm position 1, holding the ejection handle control on the arm rests; arm position 2, holding the "D" ring control between the legs; and arm position 3, holding a face curtain control. Photographs of the different arm positions are shown in Fig. 4. Five different interchangeable nozzle configurations were used to simulate the plume shape of a full-scale 2174-518 rocket catapult at altitudes of sea level, 10,000, 20,000, 30,000, and 40,000 ft. The corresponding pressure ratios p_c/p_∞ at each altitude are tabulated in Fig. 5. The fixed-area-ratio nozzles were designed so that the initial turning angle of the jet plume simulated the initial turning angle of the 2174-518 rocket plume at the specified altitudes.[2] Details of the nozzles are given in Fig. 5. High pressure air, supplied to the nozzle through the center of the sting support system, was controlled remotely over a chamber pressure range from 0 to 2300 psia.

A large range of pitch angle capability was achieved by using three different model-to-sting attachment points and then pitching the model through 120 deg with a hydraulic actuator. Photographs showing the model installed in the three different sting positions are shown in Fig. 6. Model yaw angles were achieved by rotating the model and sting support system about the vertical axis with a roll mechanism installed in the top wall of the test section.

2.3 INSTRUMENTATION

An internally mounted, six-component, strain-gage balance was used to measure model forces and moments. The jet chamber pressure and temperature were measured with a 0- to 3000-psi gage transducer and a copper-constantan thermocouple, respectively. The electrical output signals from the balance, transducer, and thermocouple were transmitted through analog-to-digital converters to a Raytheon 520 computer for final data reduction while the test was in process. Also, the balance outputs were continuously recorded on a direct-writing oscillograph for monitoring model dynamics. Two television cameras, a motion-picture camera, and a schlieren system were used to document and monitor the test.

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[2] M. Pindzola. "Boundary Simulation Parameters for Underexpanded Jets in a Quiescent Atmosphere." AEDC-TR-65-6 (AD454770), January 1965.

SECTION III
TEST DESCRIPTION

3.1 PROCEDURE

After the prescribed tunnel conditions were established, jet-off and jet-on data were obtained while holding the Mach number constant and varying the model angle of attack at discrete model yaw angles. Various model installations permitted data to be obtained through 360 deg of pitch for each of the three different arm positions. Five different nozzles were used to simulate the rocket plume shape at altitudes of sea level, 10,000, 20,000, 30,000, and 40,000 ft. The model was tested at free-stream Mach numbers of 0.6, 0.9, 1.2, and 1.5 through a model pitch range of 360 deg and yaw angles up to 45 deg. The dynamic pressure varied from 62 to 530 psf and the Reynolds number per foot varied from 0.48×10^6 to 2.40×10^6.

3.2 DATA REDUCTION

The force and moments were corrected for weight tares and reduced to coefficient form in the body axis system as shown in Fig. 7. The moment coefficients are referred to the model reference center-of-gravity position shown in Fig. 3. All force and moment coefficients are based on the seat height of 2 ft and projected model frontal area of 1.73 ft^2. The force and moment coefficients do not include the jet reaction force.

3.3 PRECISION OF MEASUREMENTS

An estimate of the accuracy of measurements is presented below:

M_∞	$\pm M_\infty$	$\pm\alpha$	$\pm\psi$	$\pm C_A$	$\pm C_N$	$\pm C_Y$	$\pm C_\ell$	$\pm C_m$	$\pm C_n$
0.6	0.005	0.1	0.1	0.008	0.05	0.020	0.006	0.008	0.003
1.5	0.016	0.1	0.1	0.003	0.02	0.008	0.002	0.003	0.001

SECTION IV
RESULTS AND DISCUSSION

This investigation was conducted for the purpose of obtaining the aerodynamic characteristics of an ejection seat escape system at transonic flight conditions through a model angle-of-attack range of 360 deg and model yaw angles up to 45 deg. The results were obtained for both simulated rocket-off and rocket-on conditions with the crew member's arms simulating three different ejection positions. High pressure air was used to simulate the escape rocket jet plume at altitudes from sea level to 40,000 ft.

The data presented in this report represent typical test results obtained during the investigation. The complete test data were forwarded to AFFDL for final analysis.

The discrepancies in data shown at angles of attack of 120, 240, and 360 deg are caused by interference effects from the sting support system. No correction for sting

interference has been made to the data. The data at each of these angles were obtained using two model-sting positions, which resulted in two different model positions with respect to the sting. (The model is pitched to the upper pitch limit for one model-sting position and pitched to the lower pitch limit for the other model-sting position.) At the upper pitch limit, the model is in the proximity of the support system, resulting in the interference effects, whereas at the lower pitch limit the model is relatively free from support system interference. These effects become more pronounced for the jet-on condition.

4.1 BASIC MODEL AERODYNAMIC CHARACTERISTICS

Model aerodynamic characteristics in coefficient form for various model attitudes are presented in Figs. 8 and 9. The results presented are for both simulated jet-off and jet-on conditions with the crew member's arms in an ejection position holding the ejection handle control on the arm rest (arm position 1). The jet-on data shown are for a simulated sea-level jet plume shape.

The axial-force, normal-force, and pitching-moment coefficients versus angle of attack are presented in Fig. 8 for zero yaw angle. The magnitude of a force coefficient is largest at the angle of attack which very nearly aligns the force axis with the airstream direction, and the magnitude increases with increasing Mach number. Since the force and moment coefficients presented do not include the jet reaction forces, the differences in the jet-off and jet-on curves represent the effects of the jet plume on the aerodynamic characteristics of the model. The major effect of the jet plume occurred when the jet plume was pointed upstream, resulting in an increase in axial-force coefficient and a decrease in normal-force coefficient.

Axial-force, side-force, yawing-moment, and rolling-moment coefficients versus yaw angle at zero angle of attack are presented in Fig. 9. For these data, the most significant variations were obtained in the axial-force and side-force coefficients. Increasing the free-stream Mach number increased these force coefficients. Also, an increase in axial-force and side-force coefficients was observed for the jet-on condition as compared to the jet-off condition; however, this effect decreased with increasing Mach number. The normal-force coefficient, not shown, remained essentially constant with yaw angle. Only small variations occurred in yawing-moment and rolling-moment coefficients.

4.2 EFFECT OF JET PLUME SHAPES

The effects of different jet plume shapes on the model aerodynamic characteristics are presented in Fig. 10 for three of the five altitudes simulated. The predominant effect of the jet exhaust occurs in the angle-of-attack range where the jet plume is pointed upstream, i.e., $a \approx 120$ to 200 deg. In this range, the jet plume causes an effect of shielding the model from the free-stream flow, resulting in large variations of model forces. The shielding effect increases with increasing jet plume size (higher altitudes) and decreases with increasing Mach number. As noted previously, the interference effects from the support system can be seen as the model angle of attack approaches 120, 240, and 360 deg.

4.3 EFFECT OF CREW MEMBER ARM POSITION

Figure 11 shows the effect of changing the crew member arm position to simulate the different ejection techniques for the sea-level jet-on condition at M_∞ = 0.6 and 1.2. Since the arms are shielded from the airstream at angles of attack greater than 120 deg, no data were obtained in the 120- to 240-deg angle-of-attack range for arm positions 2 and 3. Arm position 1 produces the greater axial-force coefficient and greater negative normal-force coefficient with the model in the vicinity of zero angle of attack. The different arm positions had essentially no effect on the model pitching-moment coefficient.

SECTION V
CONCLUDING REMARKS

Tests were conducted to determine the aerodynamic characteristics of an ejection seat escape system during simulated rocket-off and rocket-on conditions at Mach numbers from 0.6 to 1.5. The following observations are a result of these tests:

1. The simulated high altitude jet plumes produced large variations of model forces when the ejection seat jet was pointed upstream.
2. Increasing the free-stream Mach number increased the magnitude of the force coefficients and decreased the effects of the jet plume.

APPENDIX
ILLUSTRATIONS

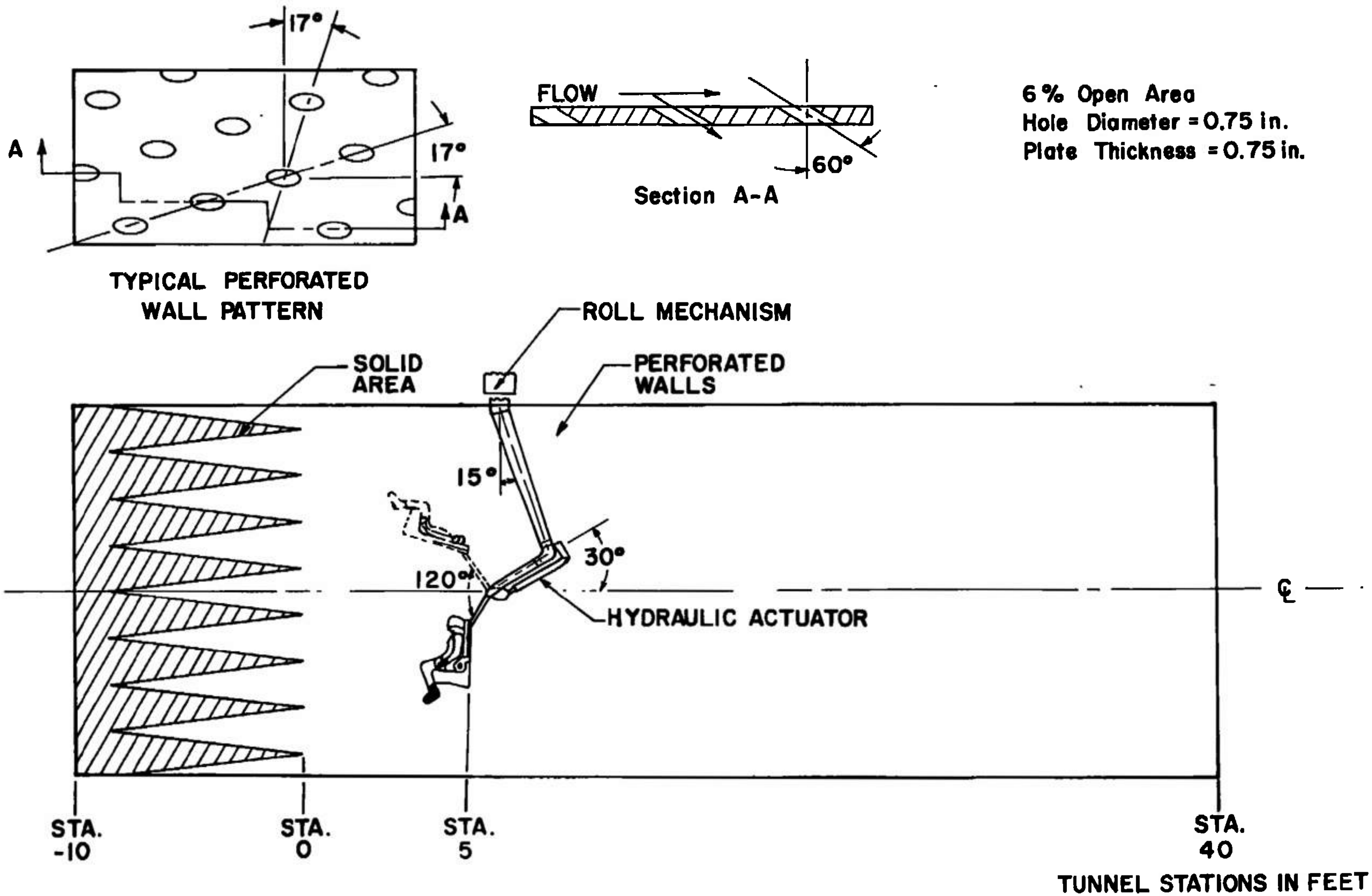


Fig. 1 Location of Model in Test Section

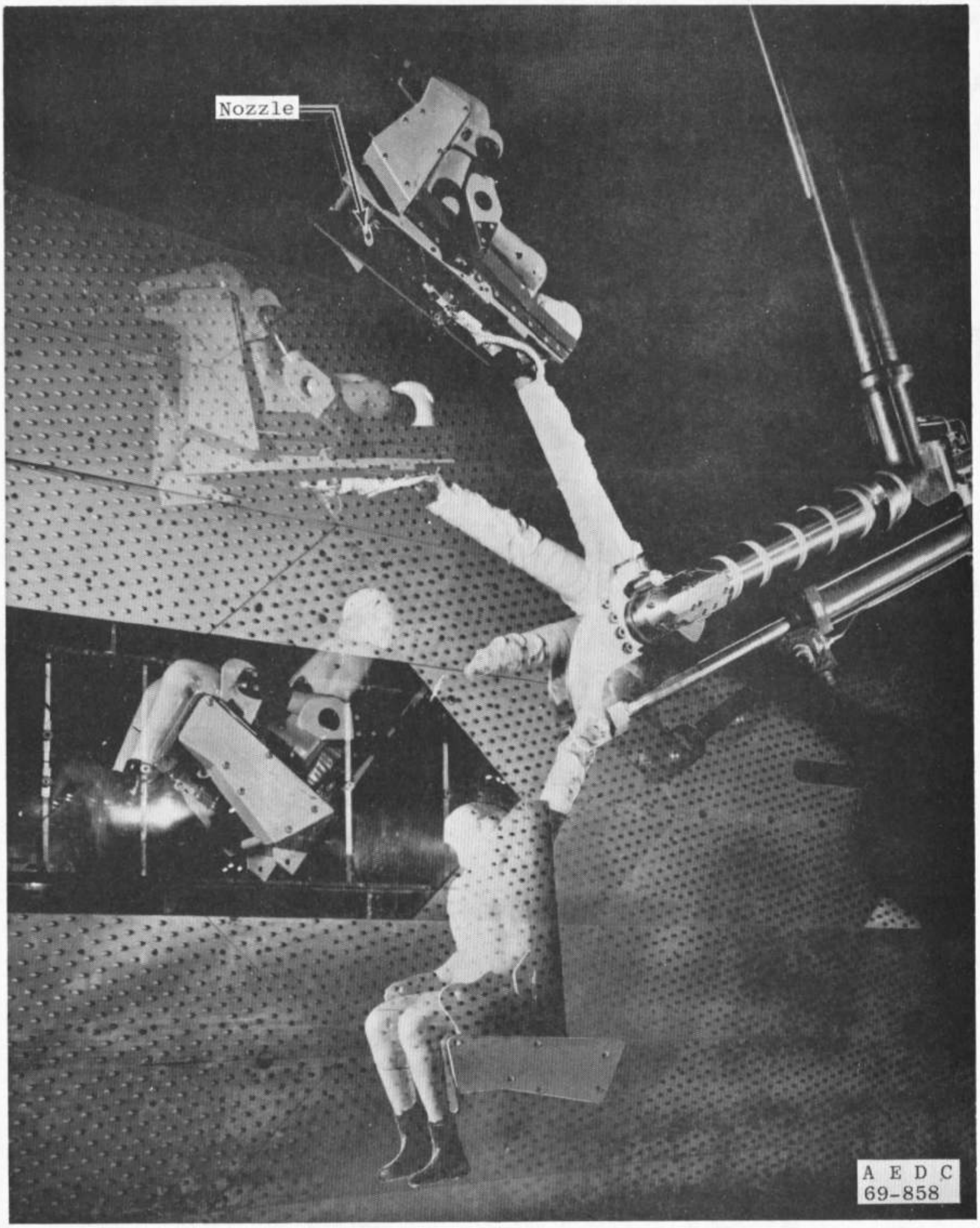


Fig. 2 Installation Photograph

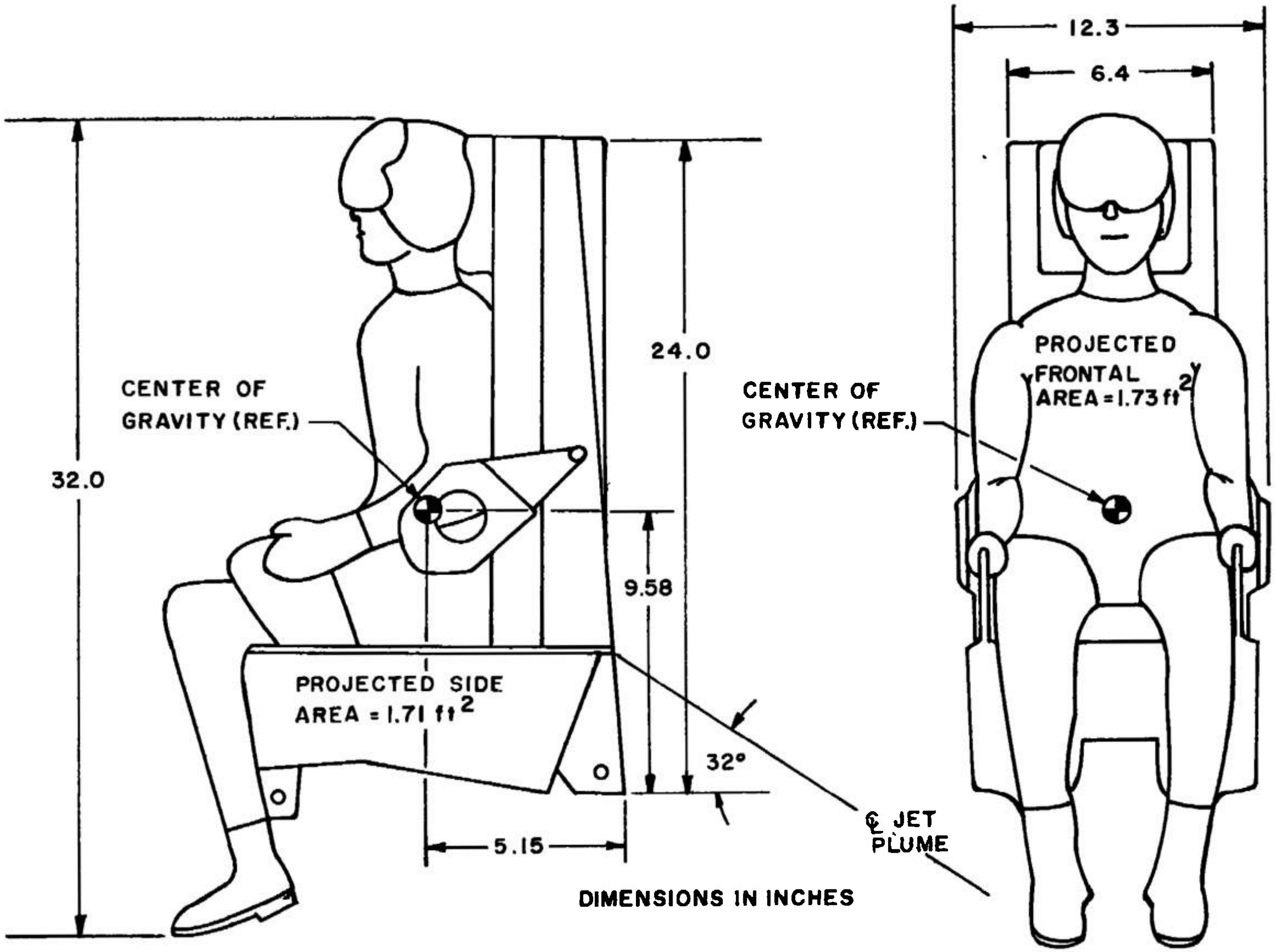
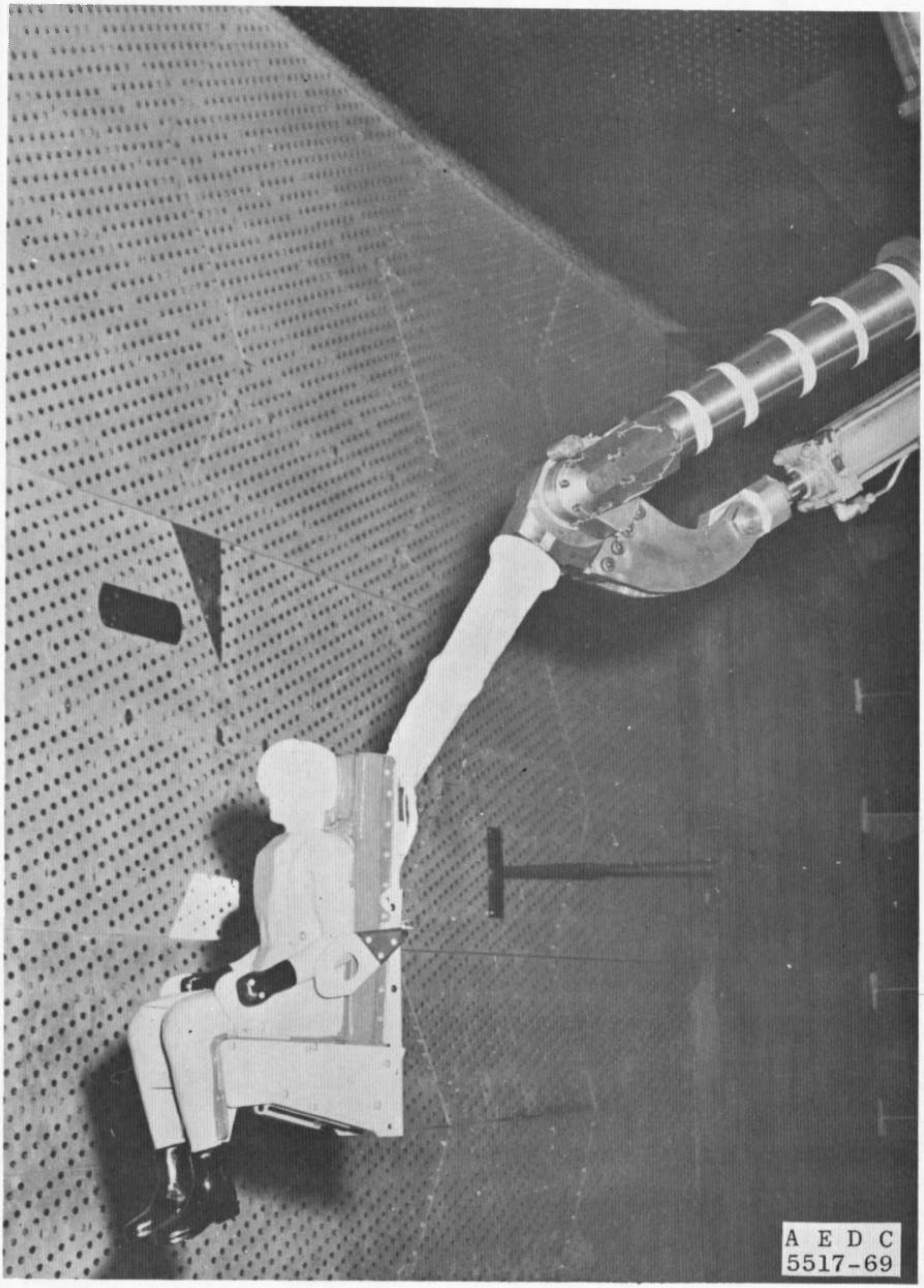
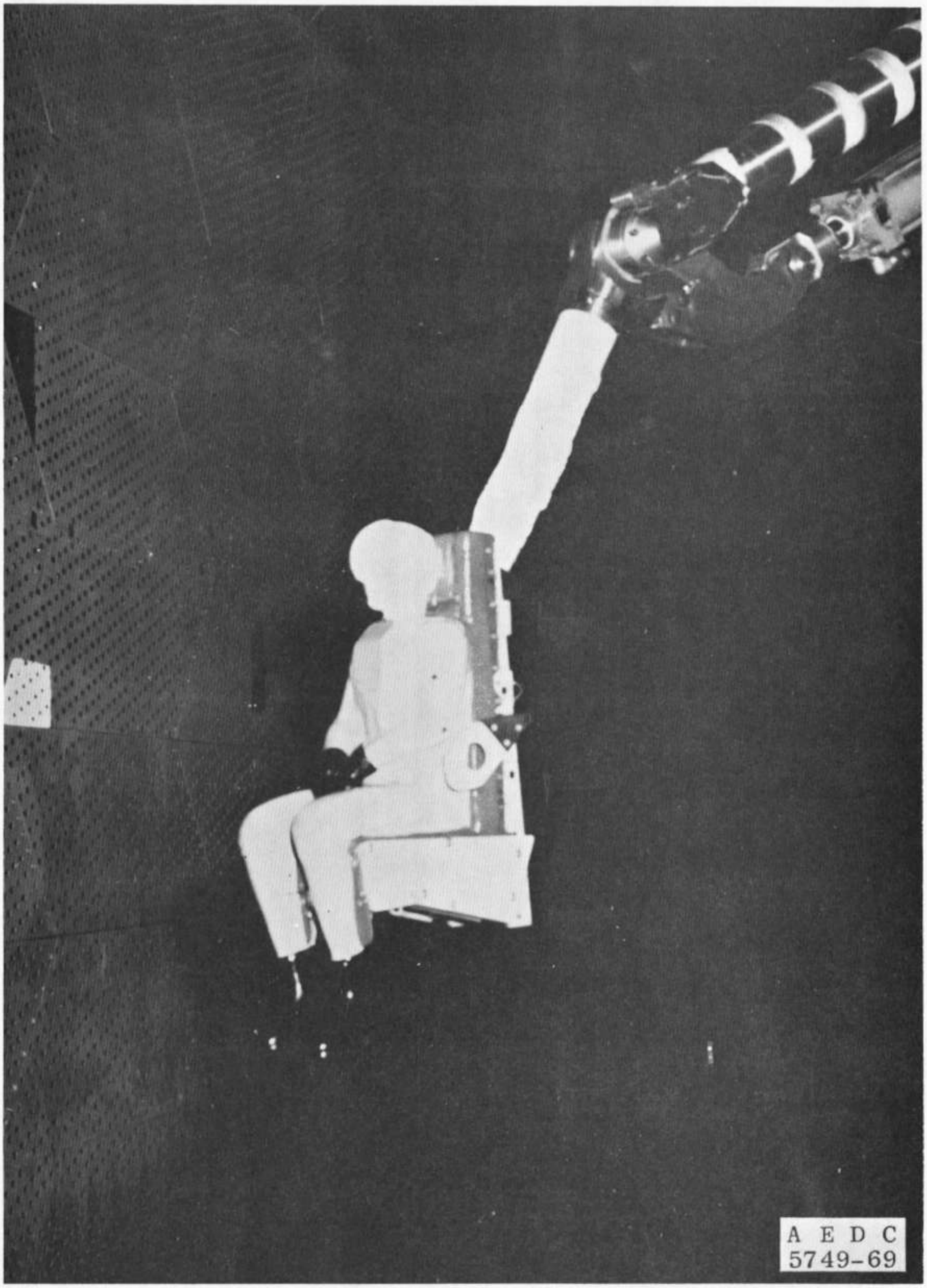


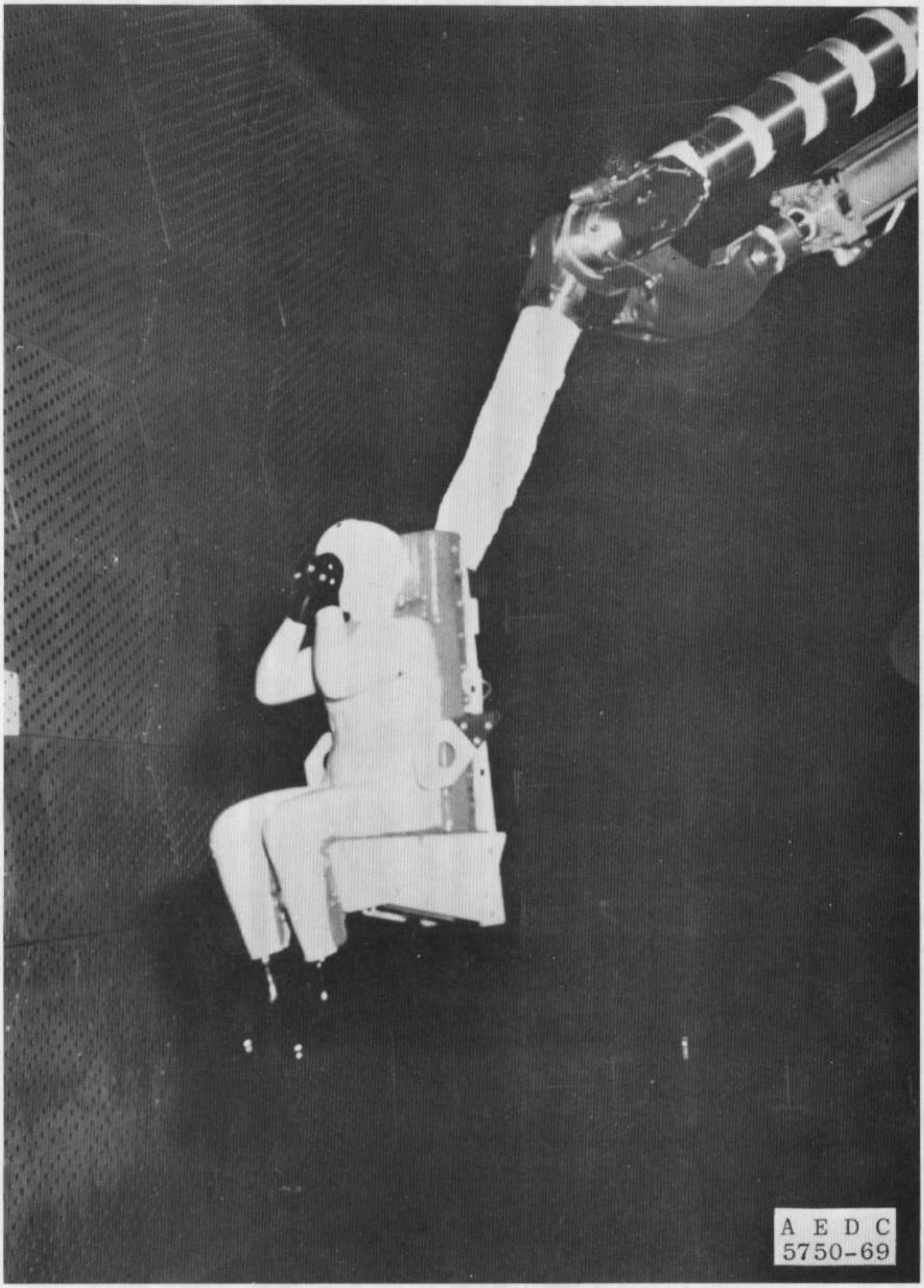
Fig. 3 Major Dimensions of the Model



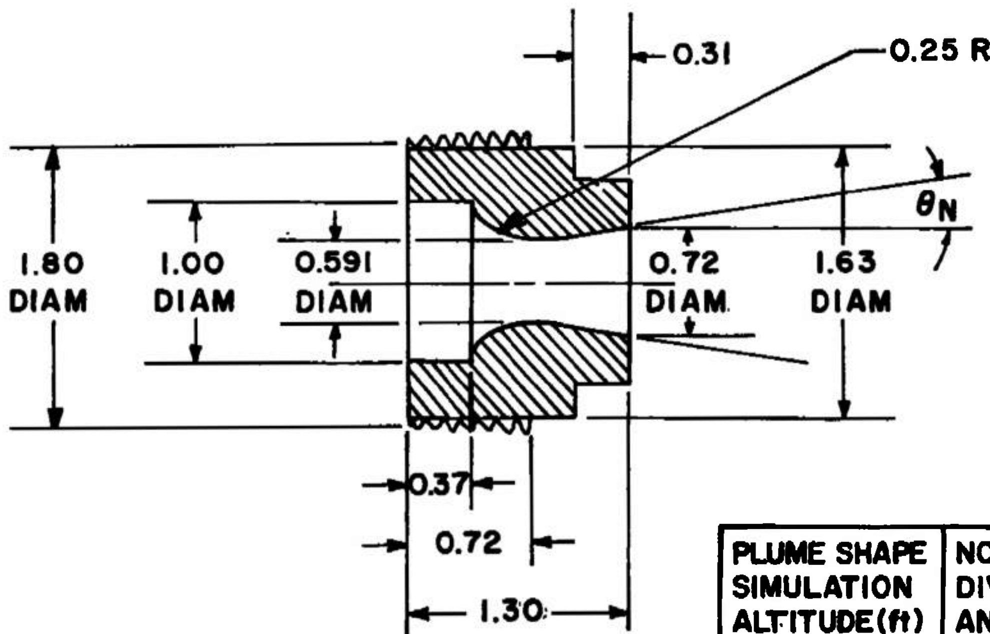
a. Arm Position 1
Fig. 4 Photographs of Crew Member Arm Positions

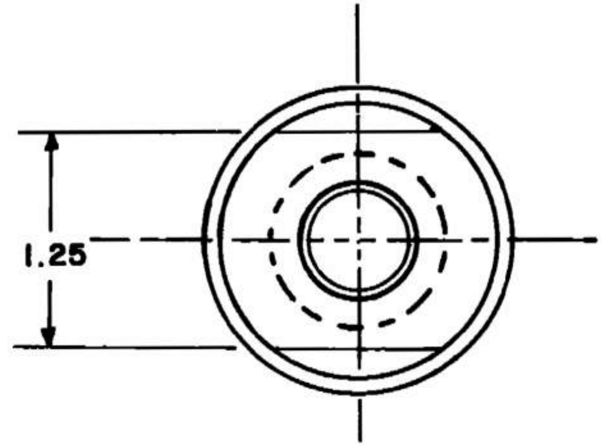


b. Arm Position 2
Fig. 4 Continued



c. Arm Position 3
Fig. 4 Concluded

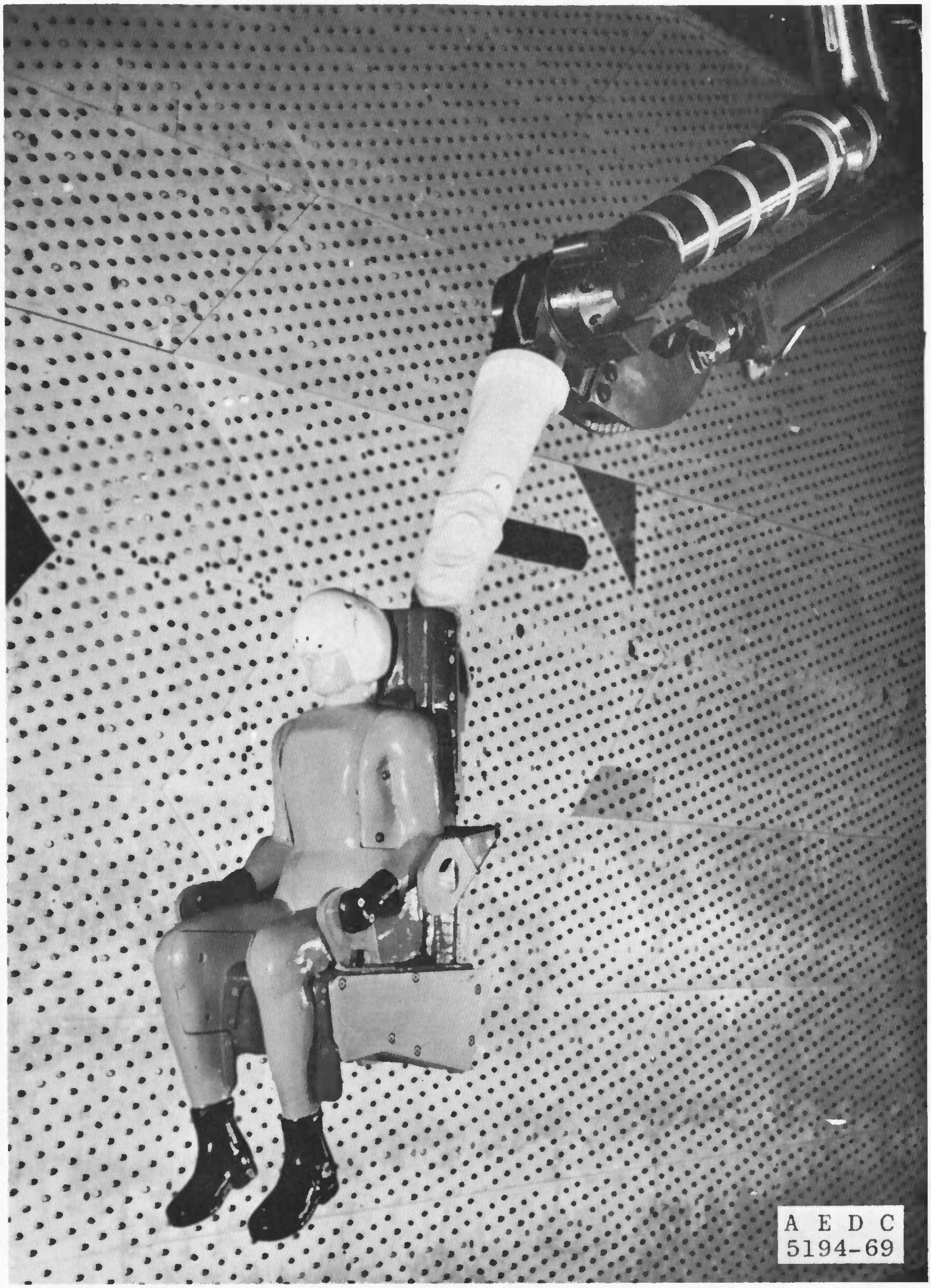




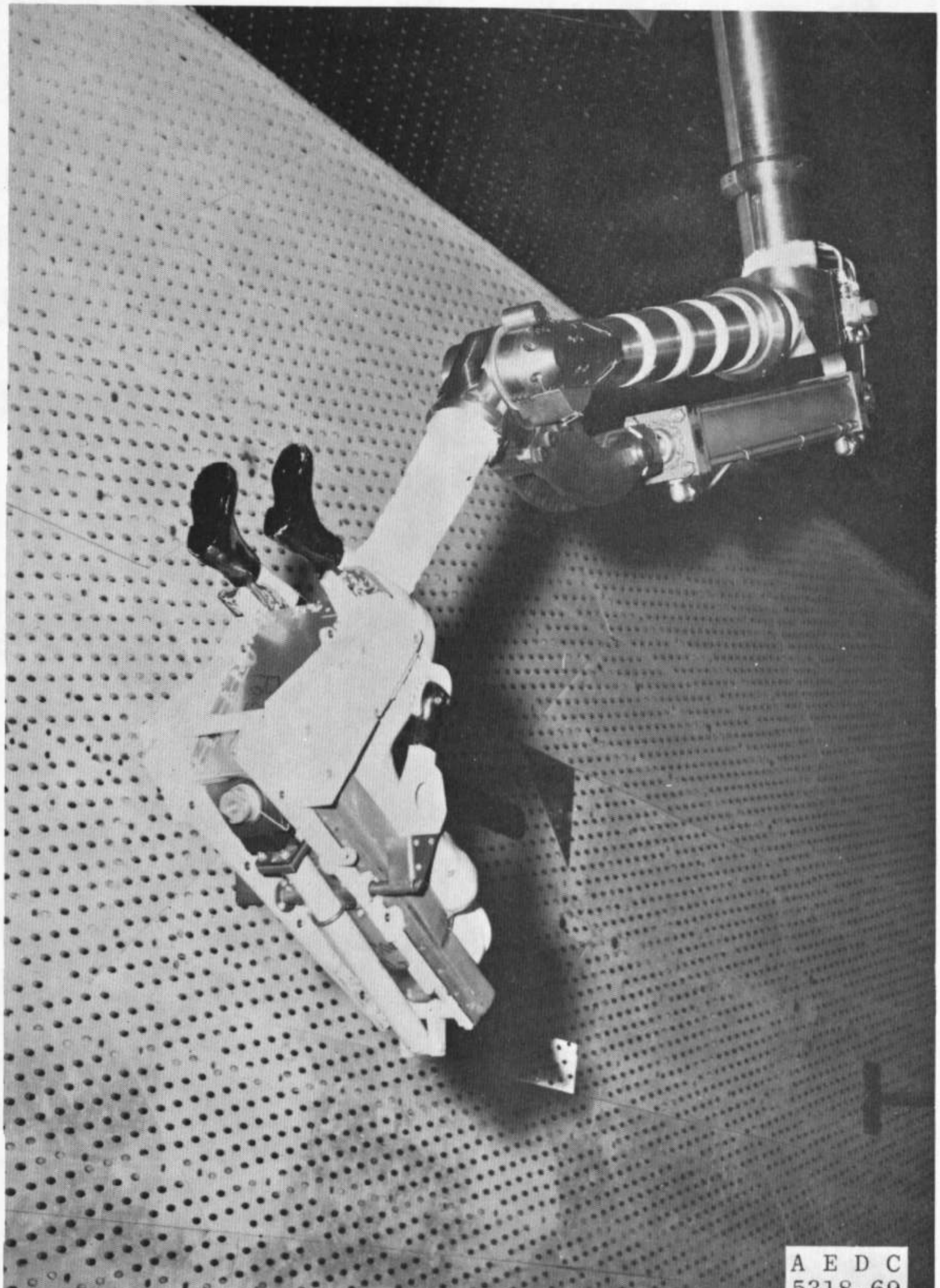
PLUME SHAPE SIMULATION ALTITUDE (ft)	NOZZLE SEMI-DIVERGENCE ANGLE, θ_N, deg	P_C/P_∞
SEA LEVEL	8.25	208
10,000	8.65	302
20,000	9.45	457
30,000	10.00	717
40,000	10.75	1162

DIMENSIONS IN INCHES

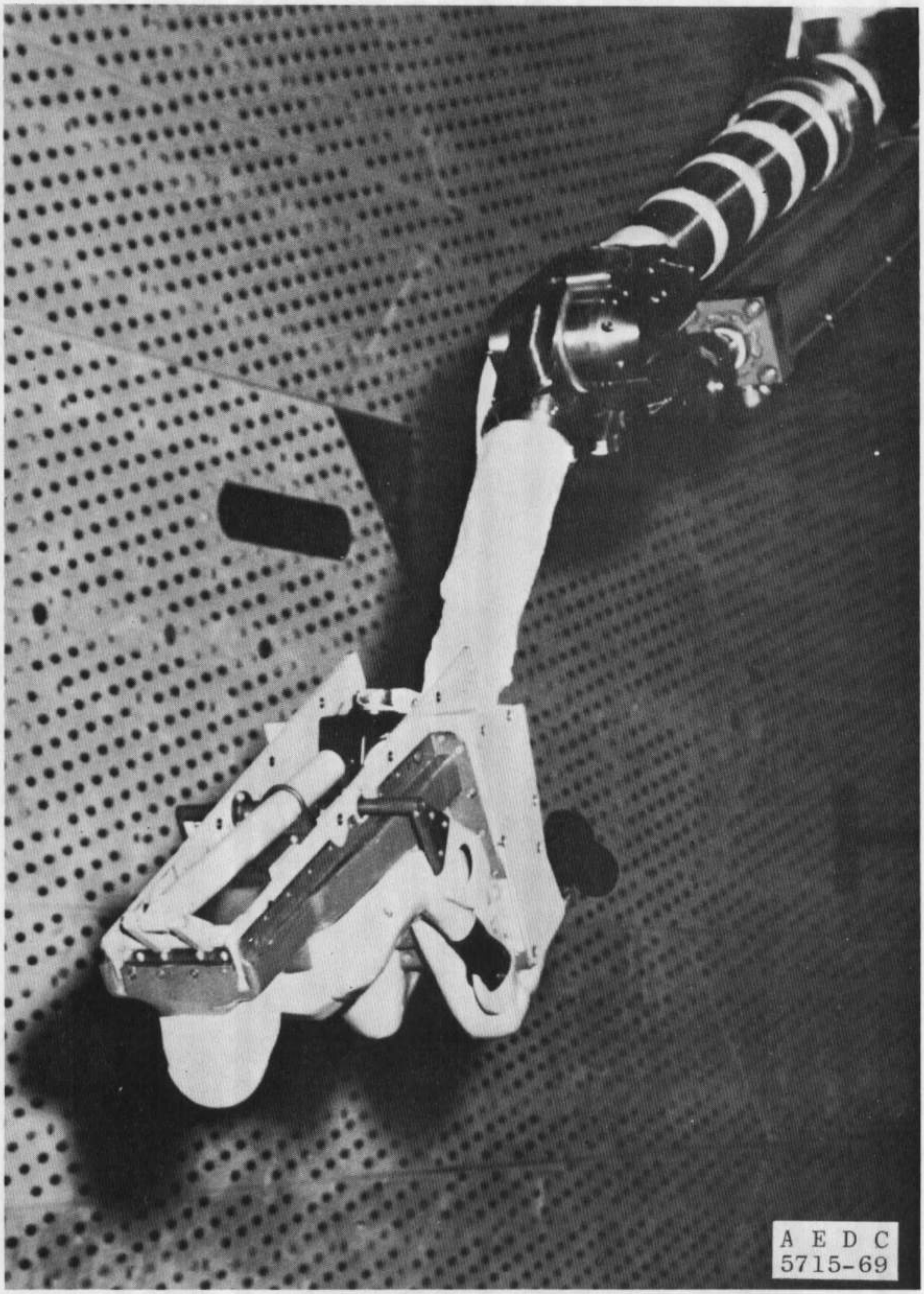
Fig. 5. Nozzle Details and Simulation Parameters



a. Model-Sting Position 1
Fig. 6 Photographs Showing Model-Sting Installations



b. Model-Sting Position 2
Fig. 6 Continued



c. Model-Sting Position 3
Fig. 6 Concluded

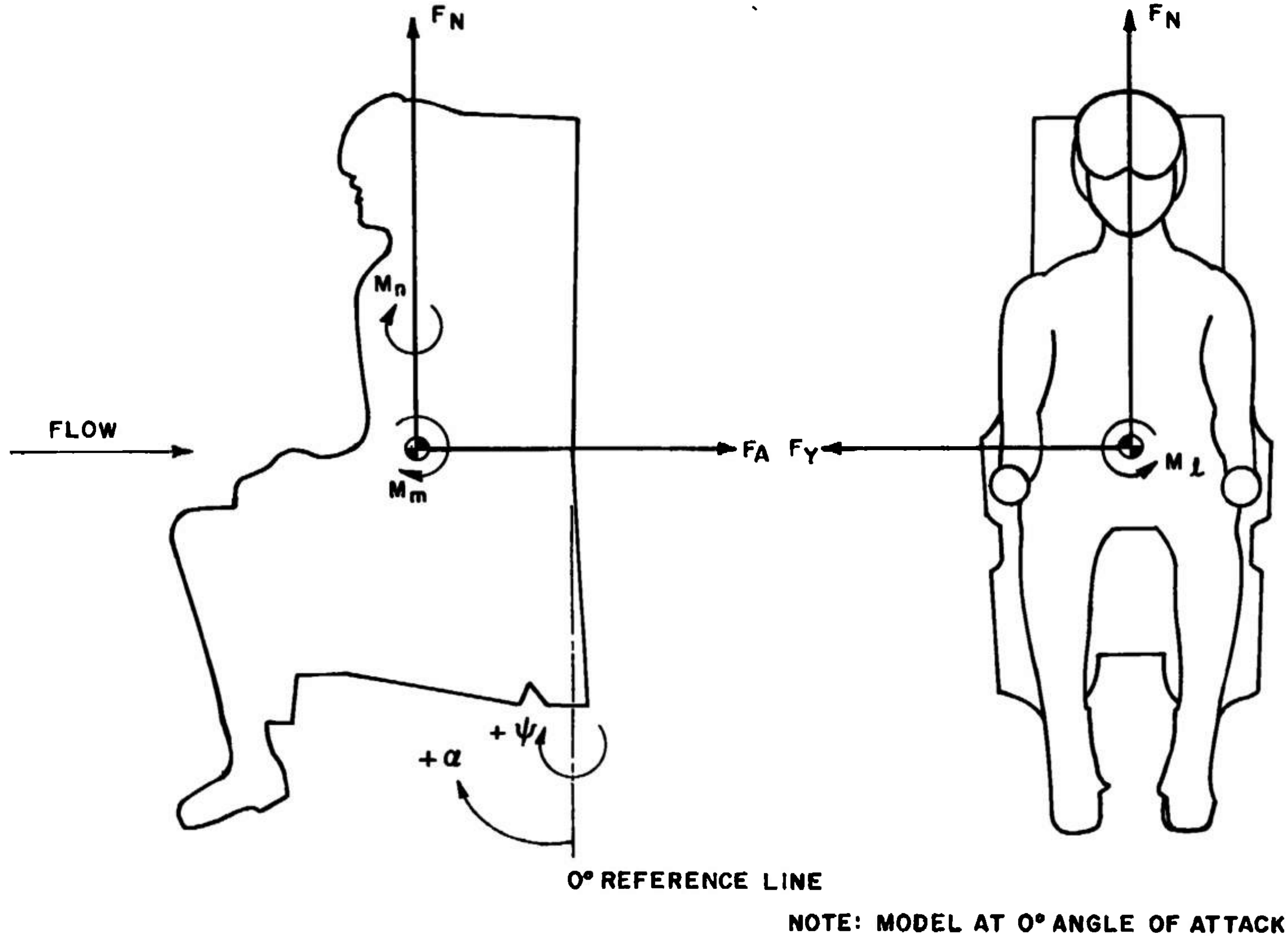
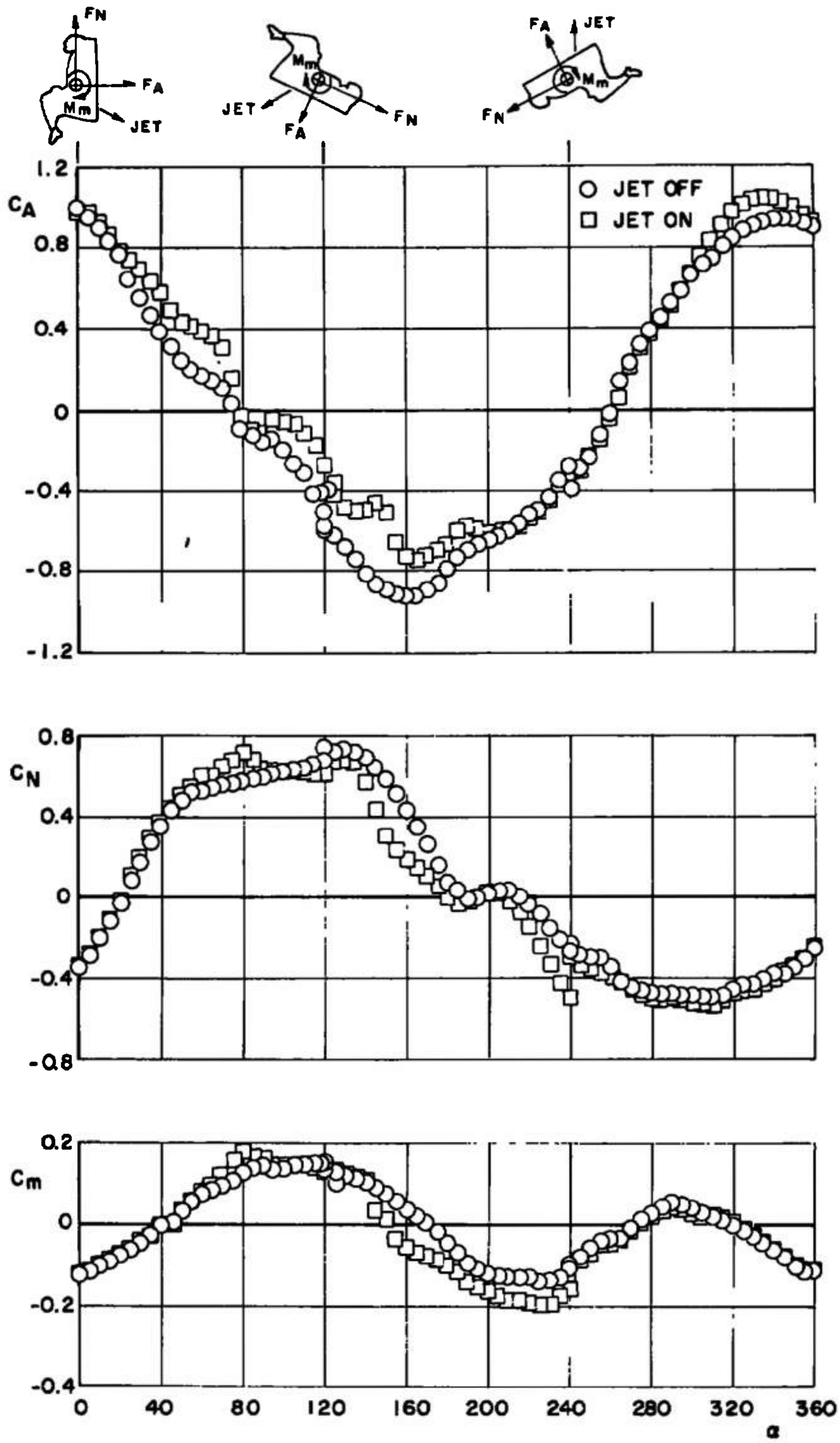
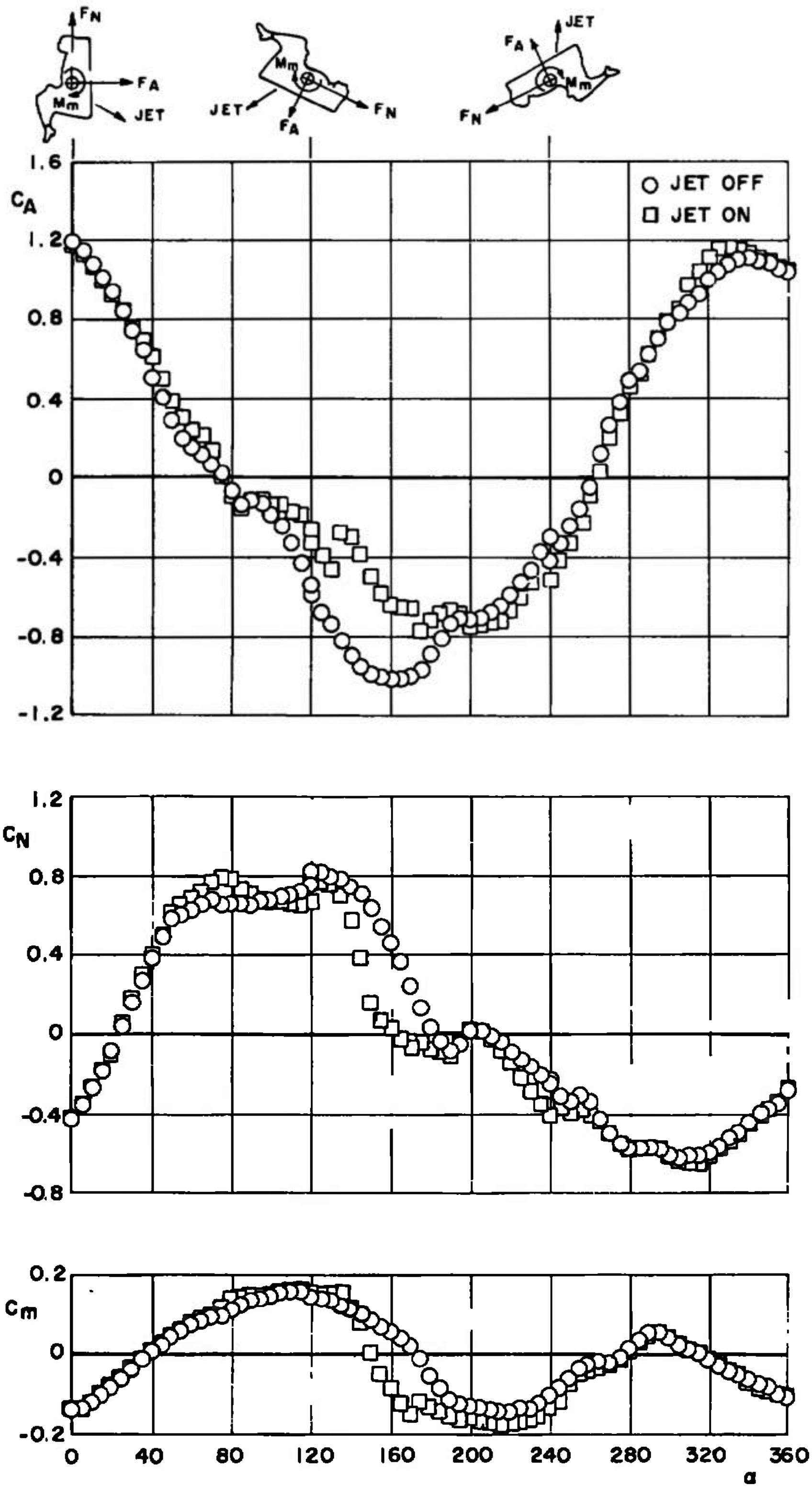


Fig. 7 Body Axis Reference System



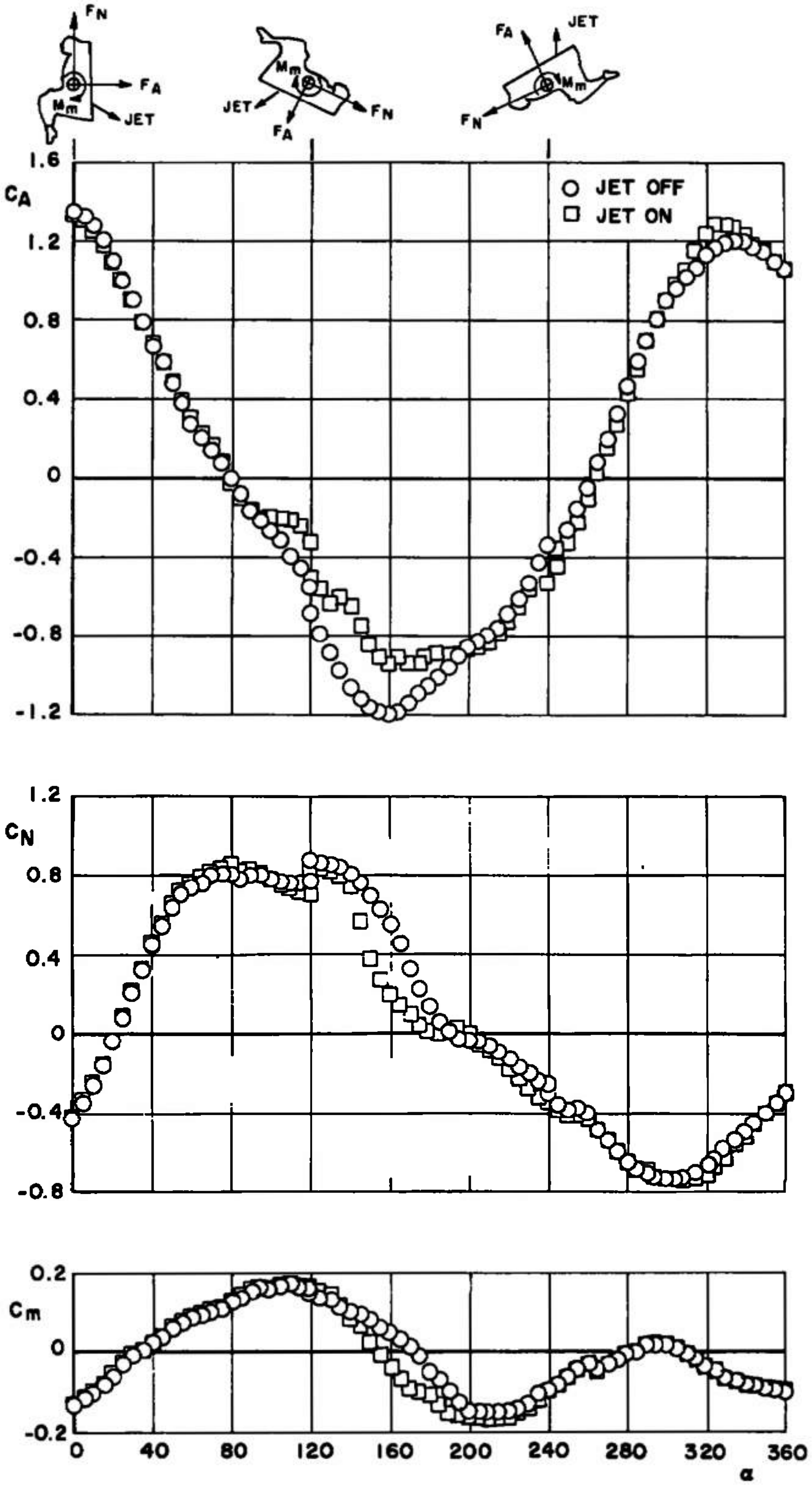
a. $M_\infty = 0.6$

Fig. 8 Variation of Force and Moment Coefficients with Angle of Attack for Jet-Off and Jet-On Conditions, Simulated Sea-Level Plume, Arm Position 1, $\psi = 0$

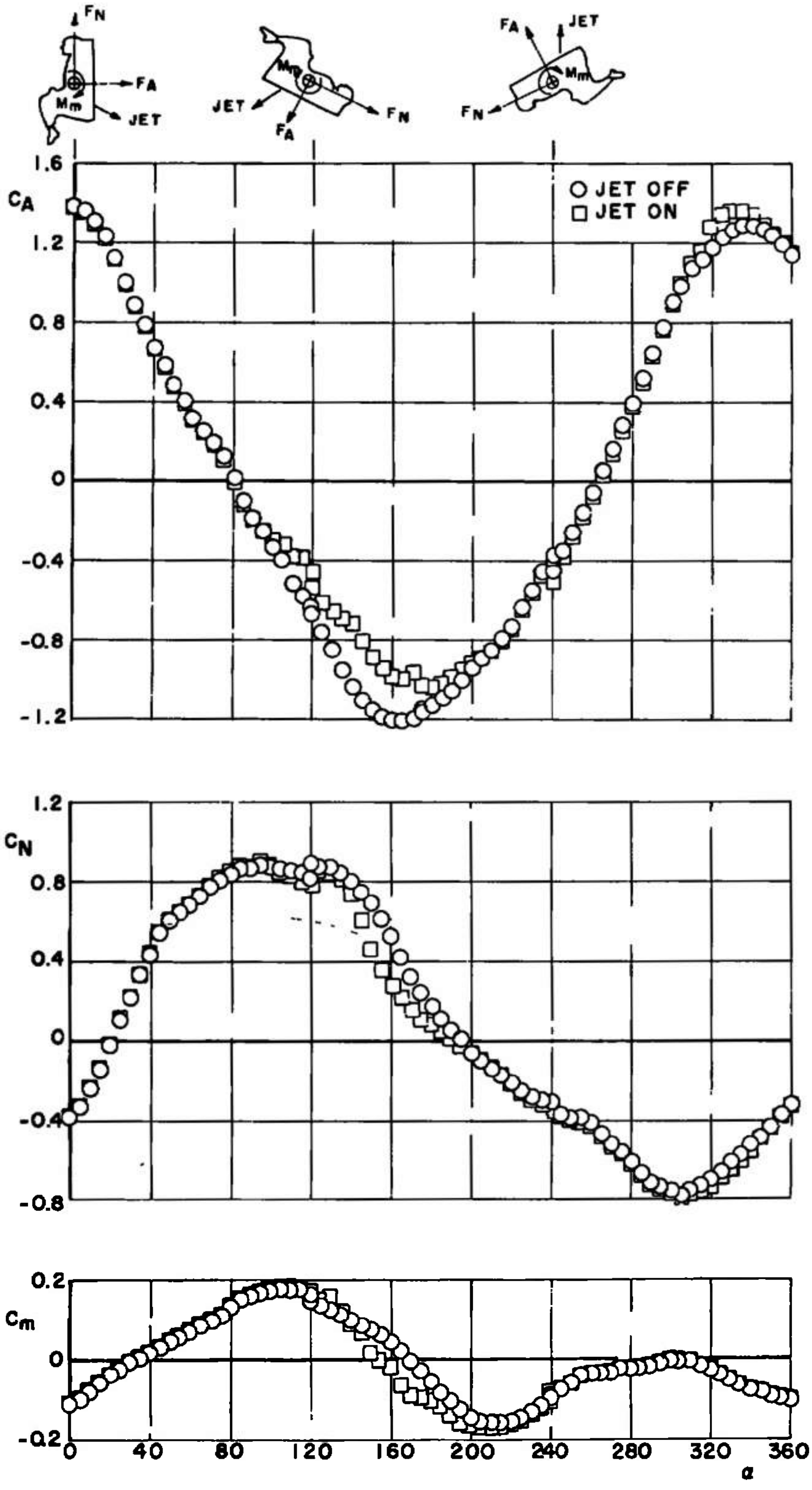


b. $M_\infty = 0.9$

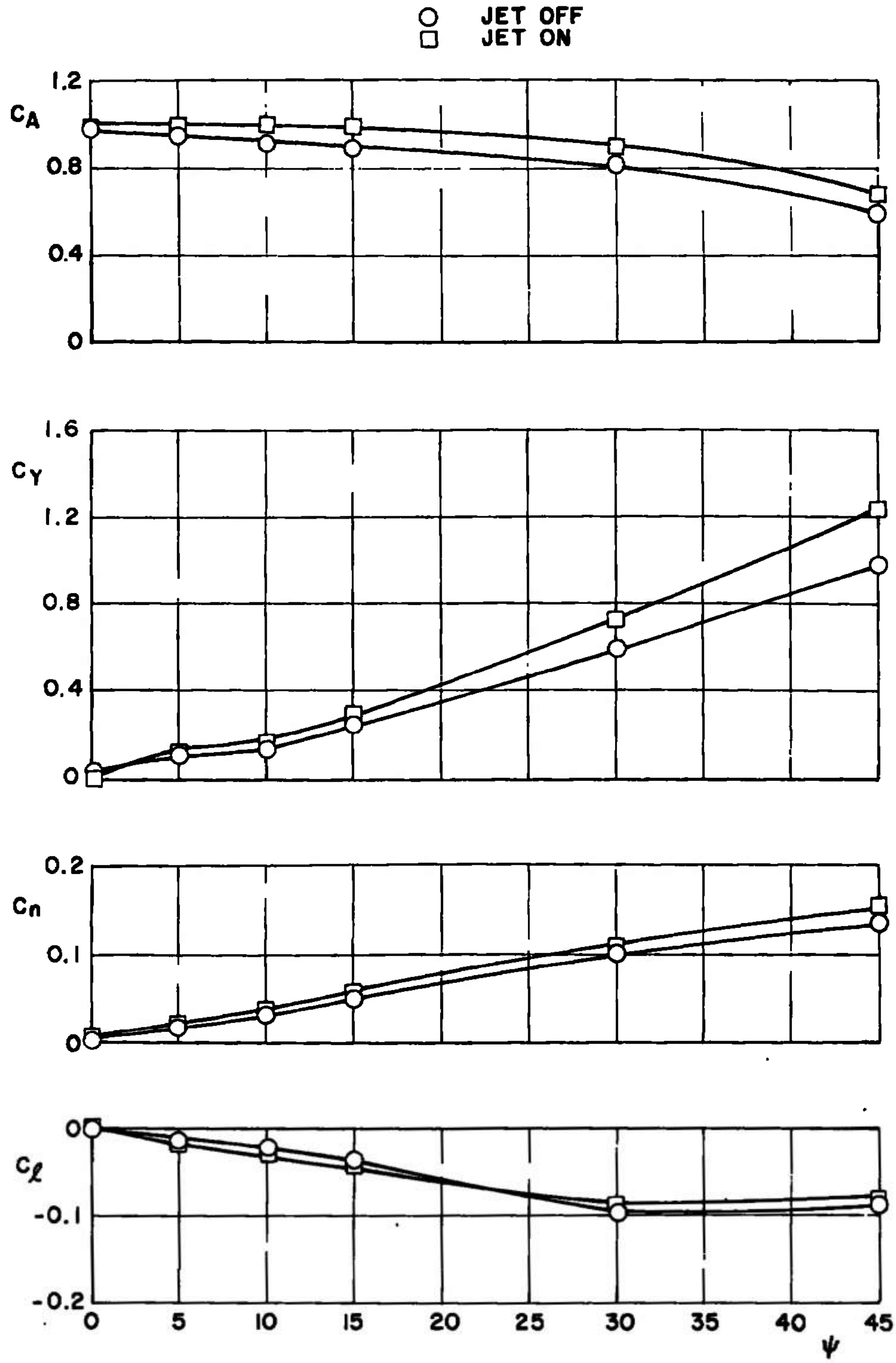
Fig. 8 Continued



c. $M_\infty = 1.2$
Fig. 8 Continued

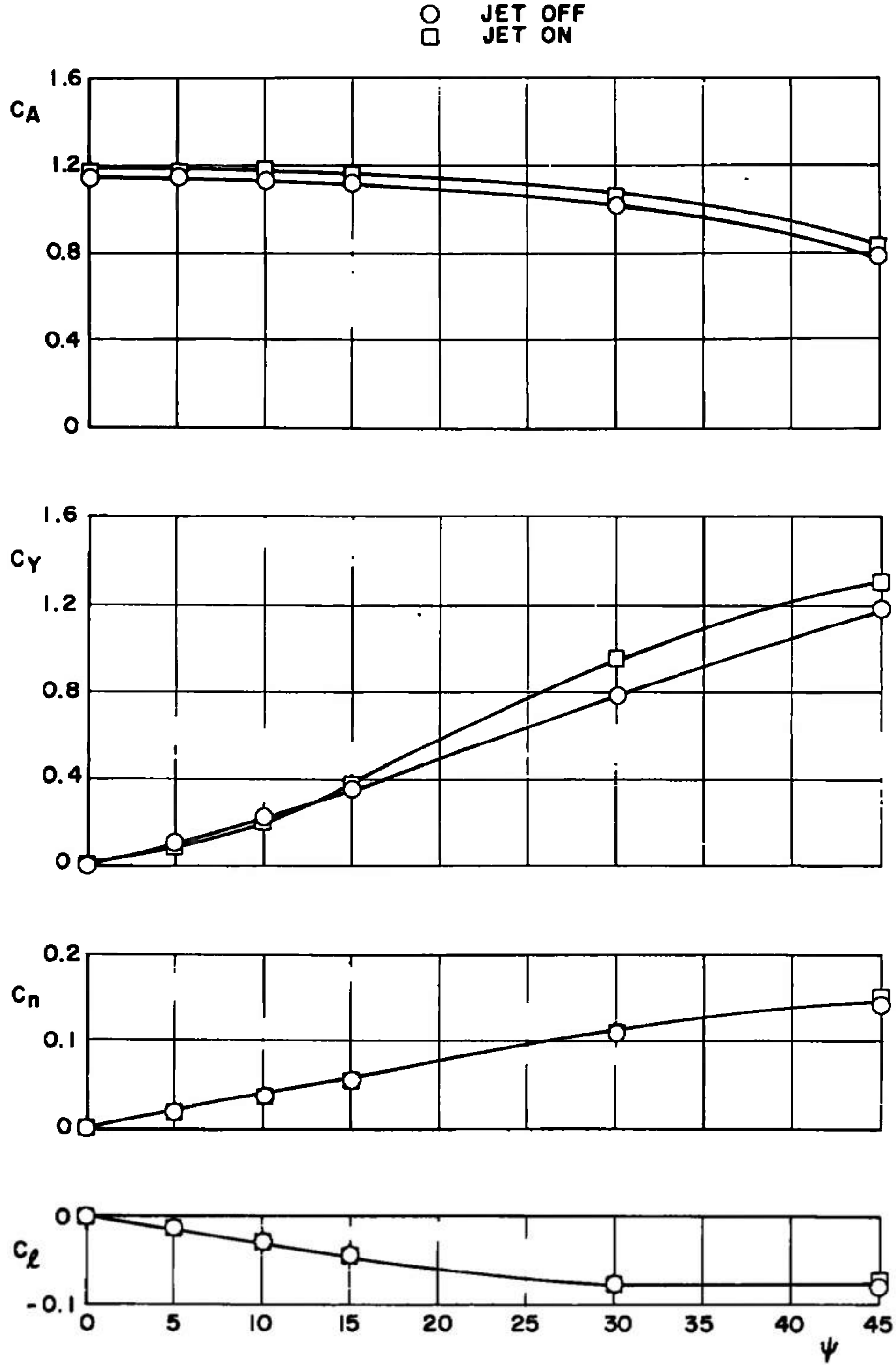


d. $M_\infty = 1.5$
Fig. 8 Concluded

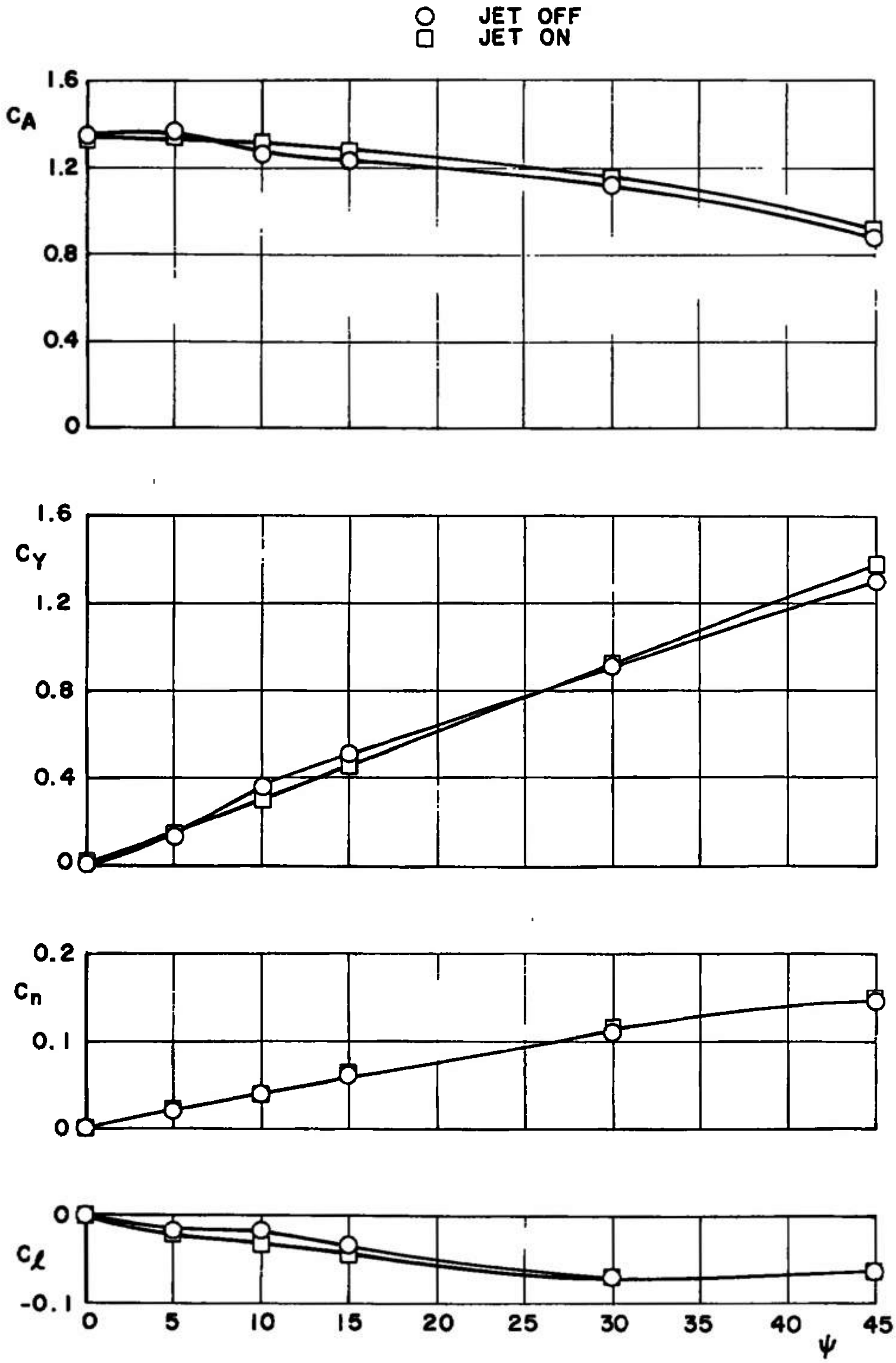


a. $M_\infty = 0.6$

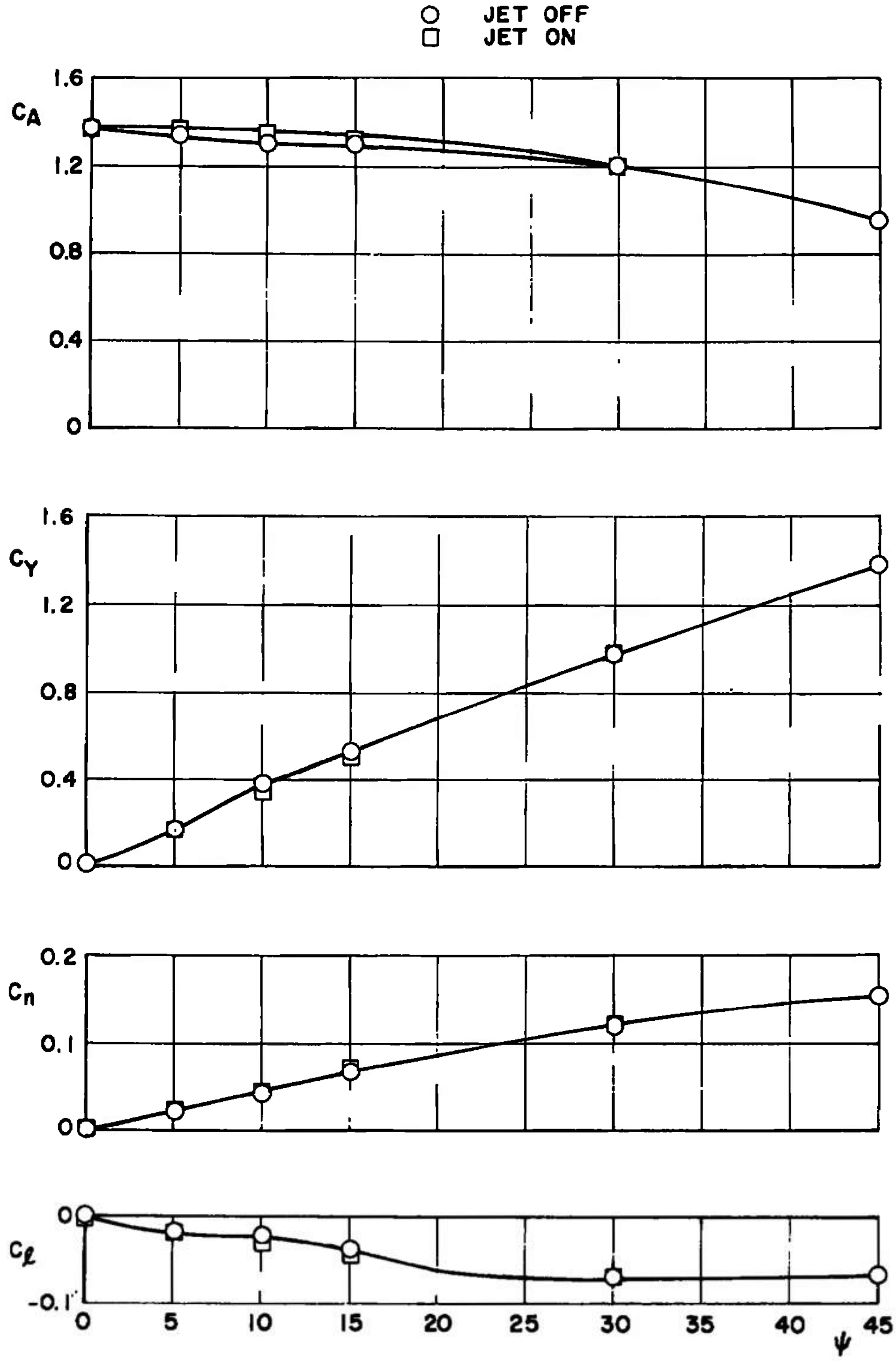
Fig. 9 Variation of Force and Moment Coefficients with Yaw Angle for Jet-Off and Jet-On Conditions, Simulated Sea-Level Jet Plume, Arm Position 1, $\alpha = 0$



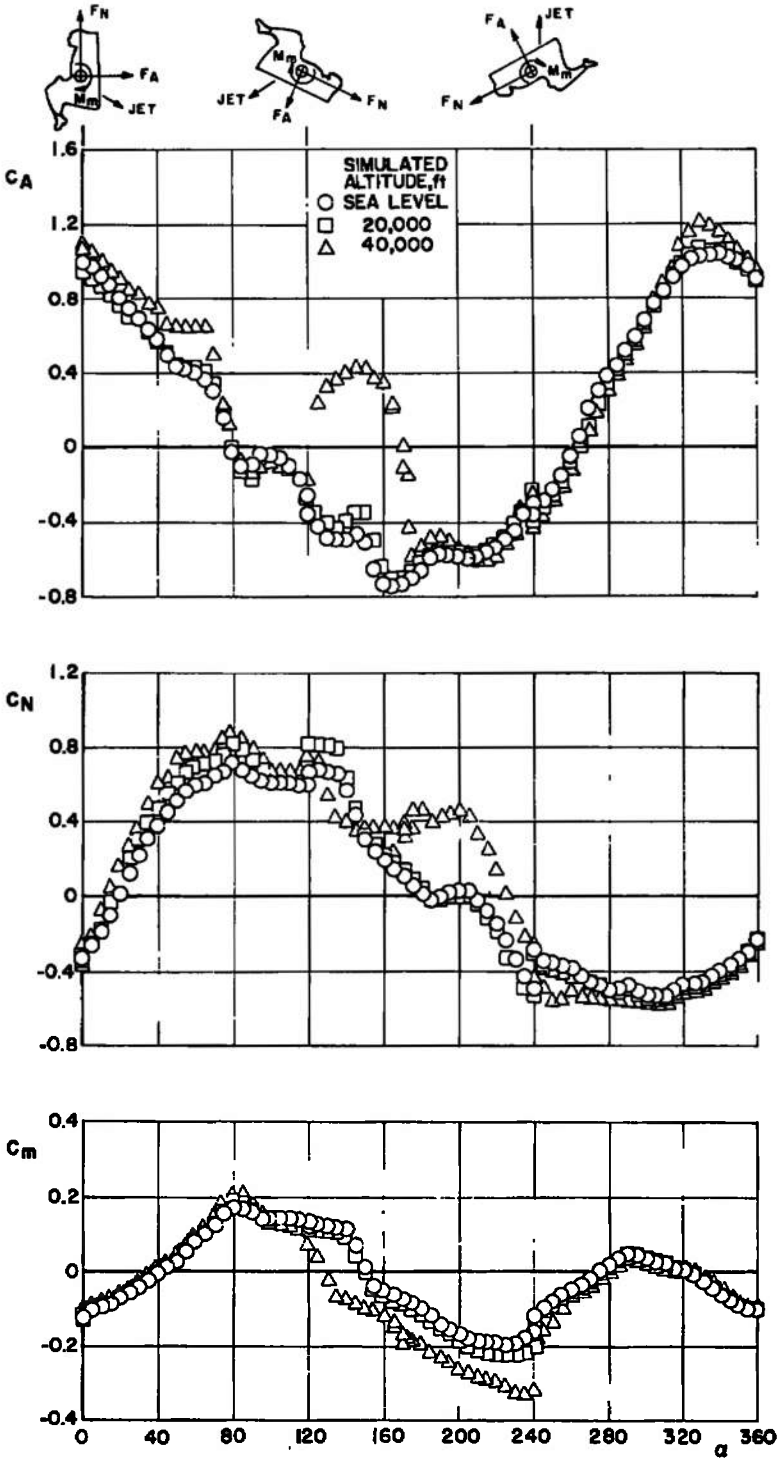
b. $M_\infty = 0.9$
Fig. 9 Continued



c. $M_\infty = 1.2$
Fig. 9 Continued

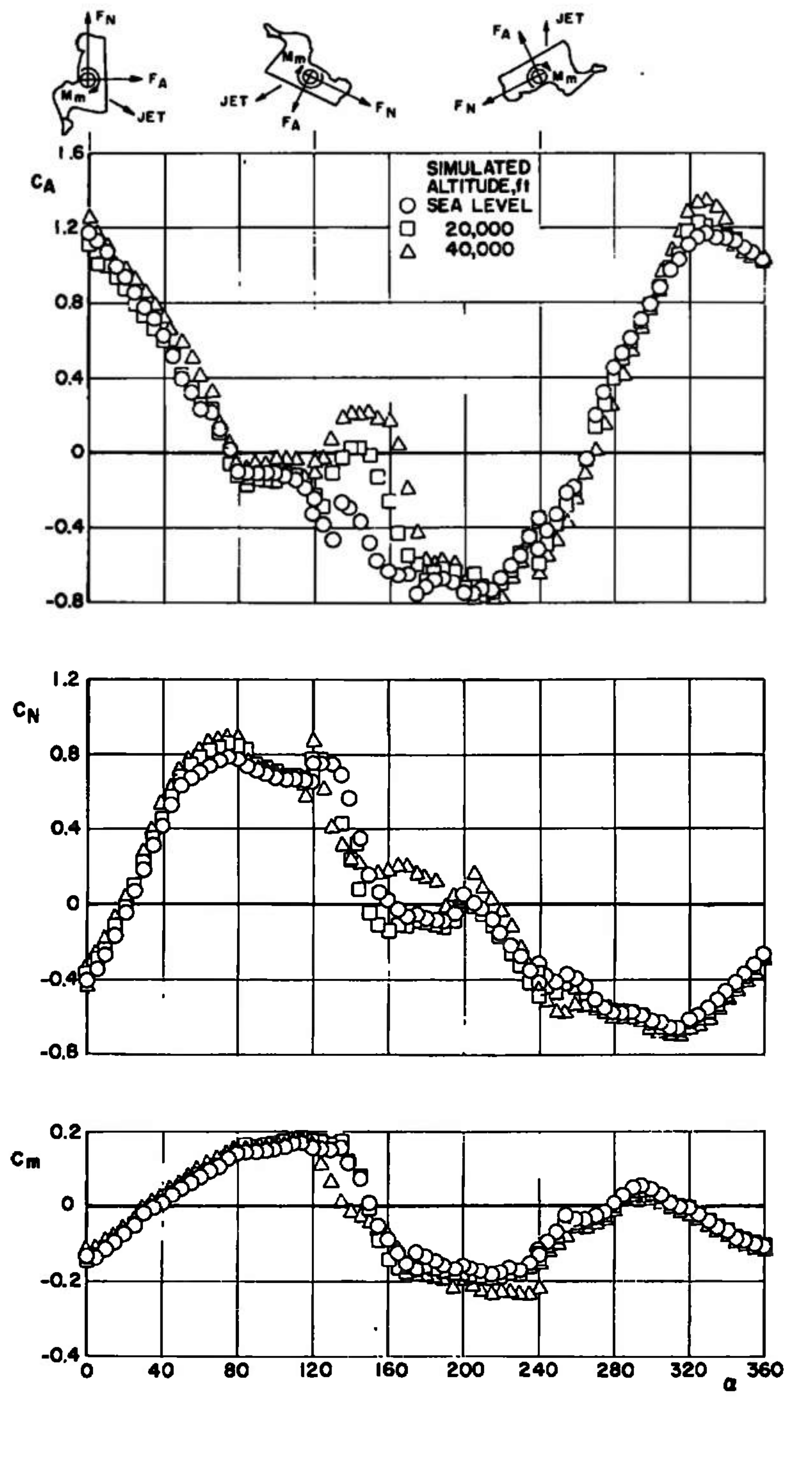


d. $M_\infty = 1.5$
Fig. 9 Concluded

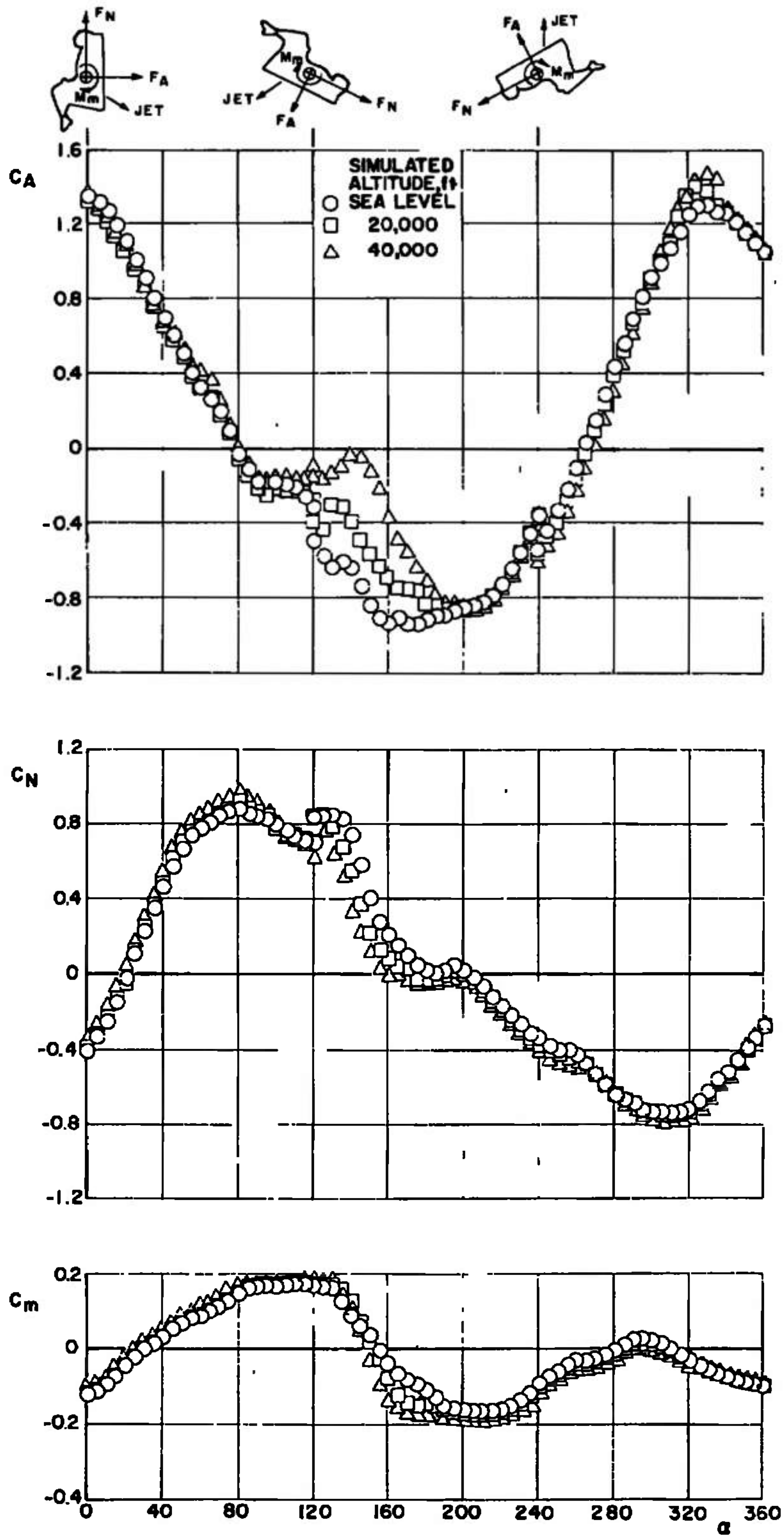


a. $M_\infty = 0.6$

Fig. 10 Variation of Force and Moment Coefficients with Angle of Attack Showing the Effects of Jet Plume Shapes, Arm Position 1, $\psi = 0$

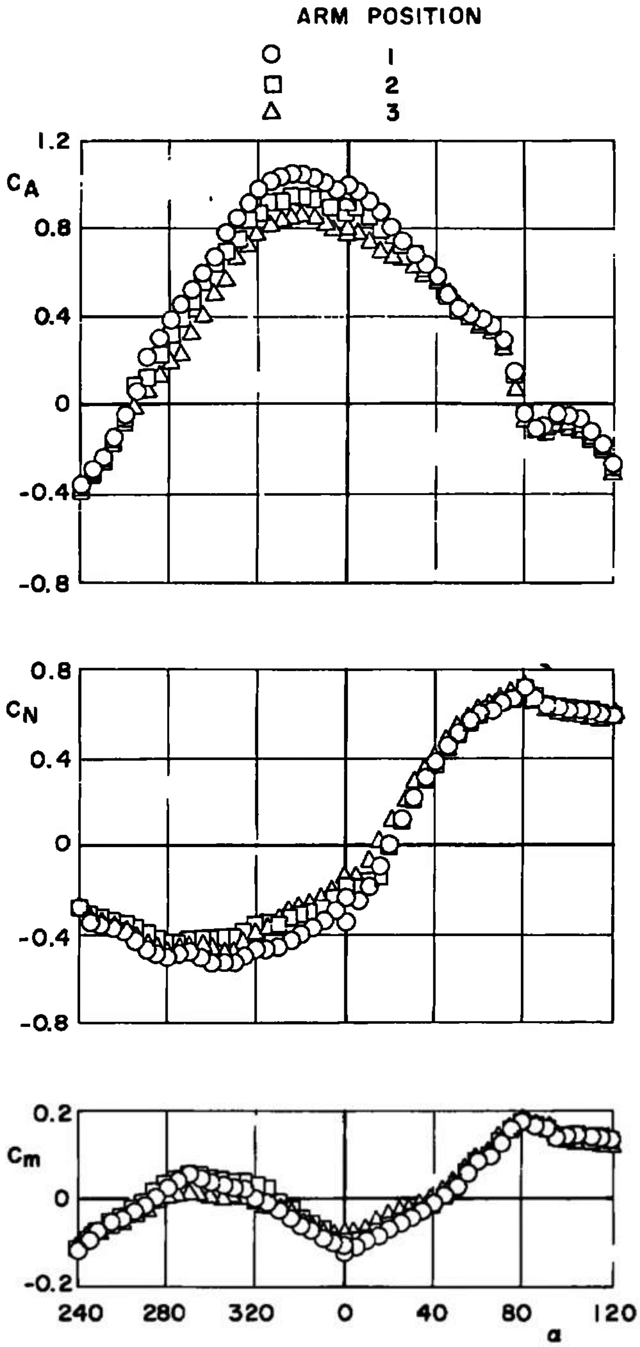


b. $M_\infty = 0.9$
Fig. 10 Continued



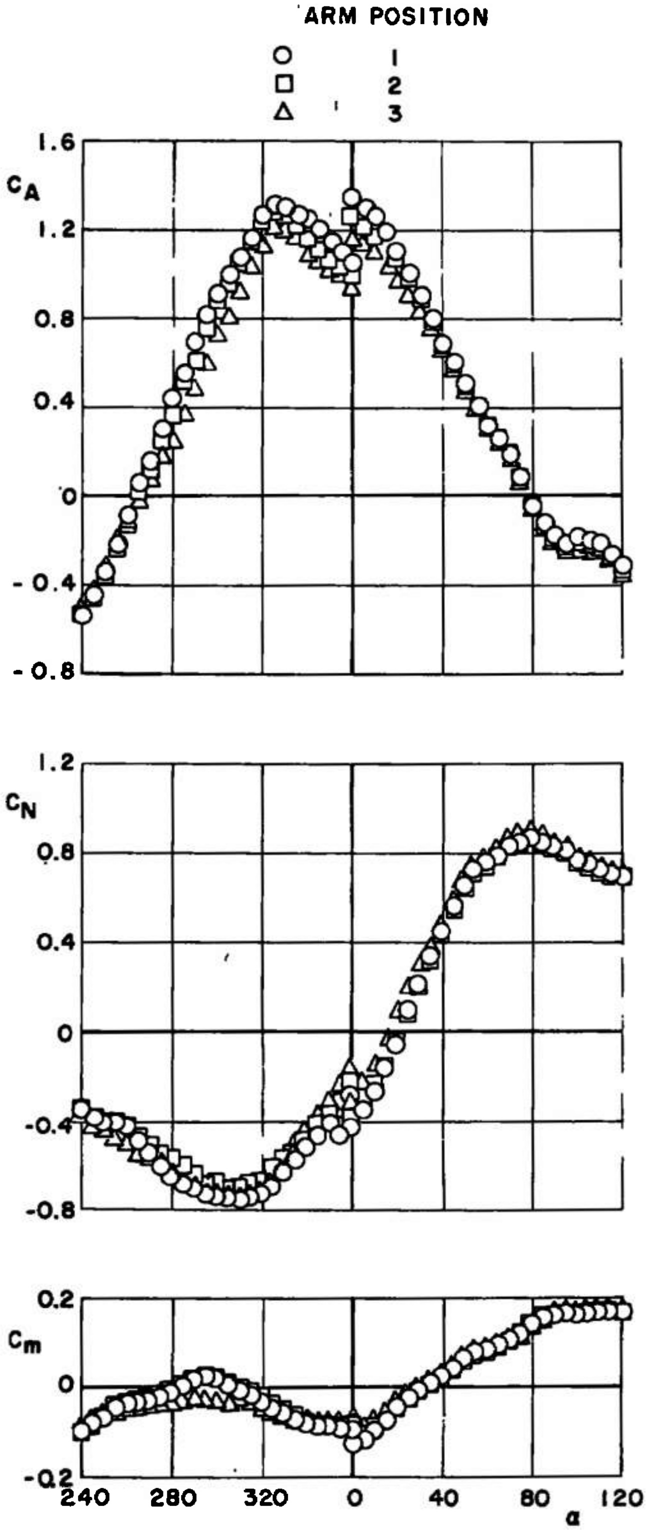
c. $M_\infty = 1.2$

Fig. 10 Concluded



a. $M_\infty = 0.6$

Fig. 11 Variation of Force and Moment Coefficients with Angle of Attack Showing the Effects of Various Crew Member Arm Positions for Jet-On Conditions, Simulated Sea-Level Jet Plume, $\psi = 0$



b. $M_\infty = 1.2$
Fig. 11 Concluded

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

A test was conducted in the 16-ft transonic wind tunnel of the Propulsion Wind Tunnel Facility to determine the aerodynamic characteristics of a 0.5-scale ejection seat escape system with a dummy crew member attached during simulated rocket-off and rocket-on conditions. Results were obtained at free-stream Mach numbers of 0.6, 0.9, 1.2, and 1.5 through a model angle-of-attack range of 360 deg and model yaw angles up to 45 deg. High pressure air was used to simulate the escape rocket jet plume at altitudes from sea level to 40,000 ft. The results show that the simulated high altitude jet plumes produced large variations of model forces when the jet was pointed upstream.

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